SCIENCE FOR CERAMIC PRODUCTION

CONTROLLING THE DEFORMATION BEHAVIOR OF THERMOPLASTIC SLIPS WITH ULTRASOUND

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The effect of ultrasound on the deformation properties of thermoplastic slips was investigated. It was shown that in treatment with ultrasound, the change in the plastic strength of beryllium oxide – thermoplastic binder casting system in the process temperature range (40 – 55°C) was due to cavitation and dissipative heat release effects and can be characterized with the equation for a thermal activation process.

Casting of thermoplastic slips is still the basic method of molding ceramic articles of complex shape and articles in the shape of tubes and rods [1]. This technology is characterized by relative simplicity of implementation and high reproducibility. However, until now, manufacturing a series of articles of complex shape (thick-walled, multichannel, irregularly shaped, etc.) from nonplastic highly heat-conducting materials, beryllium oxide in particular, has been difficult.

The complexity of obtaining quality articles in this case is due to ineffective control of casting deformation behavior with existing regime-process solutions in the 40 – 55°C temperature range, where up to 80% of the volume changes related to shrinkage of the slip occurs [2]. As a result, the required completeness of compensation for shrinkage, which affects the quality of the casts, reproducibility, and yield of acceptable articles, is frequently not attained in practice. In consideration of the complicated situation, the problems related to controlling the deformation behavior of discrete pulsed energy effects are of interest and require examination [3].

We investigated the effect of intensive ultrasound on the deformation behavior of slips in the process temperature range (40 – 75°C) of hot injection molding. The studies were conducted on slips with a 10.0 – 11.7% content of binder prepared from beryllium oxide (grade N1, specific surface area of 1.57 m^2/g) and paraffin wax binder of the composition (%): 82 paraffin (grade V2), 15 wax, 3 oleic acid (grade Ch). The slips were prepared with technology that included

mixing the powder with the binder in an impeller reactor for 24 h at 80 – 85°C.

The effect of ultrasound vibrations was evaluated by the change in the plastic strength — the limiting stress above which plastic deformation begins to develop in the material. The plastic strength of the thermoplastic slips was determined on a RM-UZ ultrasound rheometer (RF Patent No. 2279058). The basic element of the instrument (Fig. 1) is the measuring cell, which consists of two coaxially installed cylinders. Both cylinders are made with ribbing on the cylindrical surface transverse to the longitudinal axis. The inner cylinder whose end is in the shape of a cone can be moved relative to the outer cylinder by shear stress applied to it by a vertical motion mechanism.
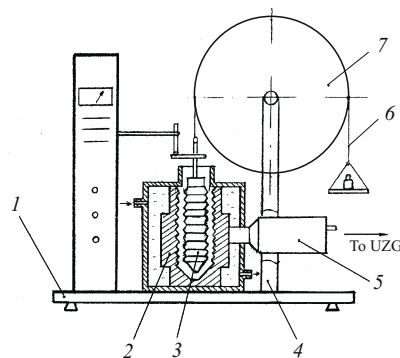
Fig. 1. Diagram of the ultrasound rheometer: *1*) platform; *2*) inner cylinder — cone; *3*) outer cylinder — waveguide; *4*) post; *5*) acoustic converter; *6*) loading unit; *7*) disk.

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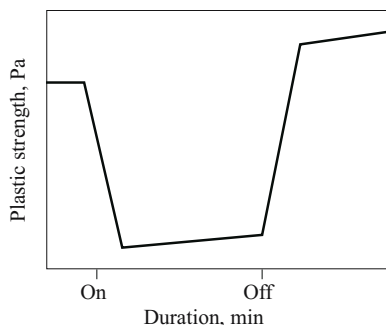
Fig. 2. Character of the change in the plastic strength in time in switching the ultrasound on and off.

Fig. 3. Slip temperature as a function of duration of ultrasound treatment at 1.2 kW power (*a*) and ultrasound power for a treatment time of 5 min (*b*).

Fig. 4. Plastic strength P_m as a function of temperature for slips treated with ultrasound (*a*) and untreated slips (*b*): *1*, *2*, and *3*) 9.5, 10.3, and 11.7% binder content.

A feature of this instrument is making the outer cylinder in the form of a longitudinal-transverse waveguide equipped with a converter at 22 kHz. The instrument is equipped with a UZG 0.6-22 ultrasound generator and a thermostat that makes it possible to thermostat the investigated system. The temperature of the walls of the measuring cell is controlled by chromel-cupel thermocouples and the temperature of the thermoplastic molding pastes was measured with a thermometer. The sequence of the measurements, processing of the results, and calculation of the plastic strength and structural-mechanical characteristics were conducted with the method in [4].

As expected, treatment with ultrasound significantly changed the plastic strength of the slip due to a number of physicochemical effects that take place in disperse structures in treatment with ultrasound. This type of effect primarily concerns the effect of breakdown of the structure, which is manifested by a sharp decrease in the plastic strength (by 2 – 2.5 times) in the initial (under 2 min) period after turning on the ultrasound for slips with a different binder content (Fig. 2).

This evolution of the process is due to the presence of gas phase in the slip, an ideal medium for the appearance of cavitation nuclei — the basic driving force that causes structural breakdown in a disperse system. The high dispersion and variety of shapes and surface relief of the solid particles in beryllium oxide powders favor the presence of gas bubbles. Collapse of cavitation bubbles with the appearance of shock waves in the liquid medium, which also destroy the coagulation structure of thixotropic character formed by molecular van der Waals forces characteristic of thermoplastic slips, takes place under the effect of the cavitation that arises in treatment of disperse systems with ultrasound [5].

A characteristic feature of the effect of structural breakdown that arises under the effect of ultrasound is its reversibility. A certain time after the ultrasound treatment stops, the value of the structural-mechanical parameters is restored to a value close to the initial value (see Fig. 2). The observed reversible change in the structural-mechanical characteristics in casting systems is confirmation that decomposition of
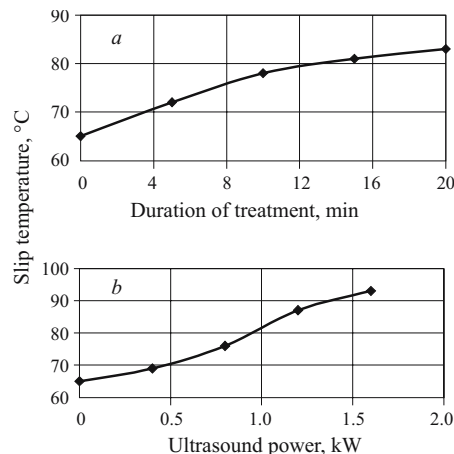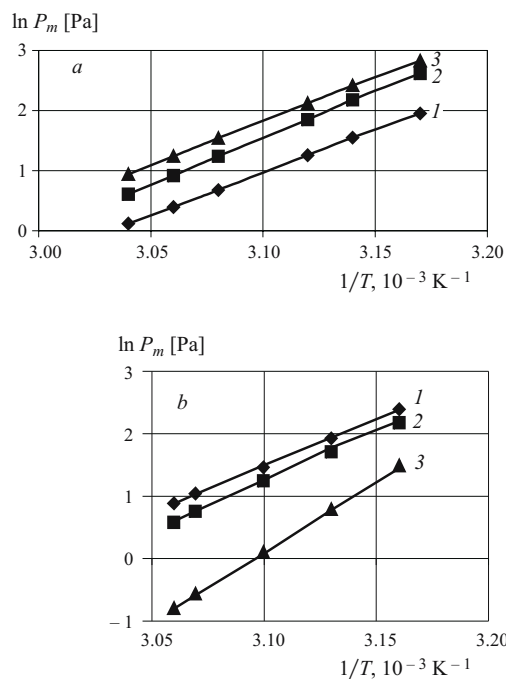
molecules of the binders does not occur during treatment of the slip with ultrasound.

In addition to the mechanical effect, treatment with ultrasound also has a thermal effect on structured dispersions, and its magnitude is a function of the duration and intensity of the treatment (Fig. 3). However, the curves of the plastic strength as a function of the temperature plotted in logarithmic coordinates are identical in character in both the treated and untreated slips (Fig. 4). In both cases, note the equality or close values of the slopes of these curves, which indicates

the unique nature of deformation of casting systems with a different content of solid and liquid phases.

In consideration of the thermally activated character of the deformation behavior of disperse systems, a physically substantiated Arrhenius equation, which has the following form in this case, can be used for evaluating the effect of dissipative heat release on the plastic strength of the slip with a sufficient degree of accuracy:

$$P_t^m = P \exp\left(-\frac{E_n}{R\sum T}\right),$$

where P_t^m is the plastic strength at a determined temperature; P is a constant; E_n is the activation energy; R is the universal gas constant; ΣT is the slip temperature after exposure to ultrasound: $\Sigma T = T + \Delta T$ (T is the slip temperature before treatment with ultrasound; ΔT is the change in the slip temperature from exposure to ultrasound).

According to the recommendations of A. A. Borzykh [6]:

$$\Delta T = \frac{2\pi^2 f^2 A^2 v \exp(-2\alpha l)[1 - \exp(-2\alpha l)]\Delta t}{c \Delta l},$$

where f and A are the frequency and amplitude of the ultrasound exposure, Hz and m; v is the velocity of the ultrasound in the slip, equal to 900 ± 100 m/sec; α is the damping factor; Δt is the duration of the ultrasound treatment, sec; Δl is the distance of the layer from the emitter, m.

The damping factor is determined with the equation:

$$\alpha = \ln(A_0/A)/l,$$

where A_0 and A are the amplitude of the vibrations at the emitter and at distance l from the emitter.

The calculations show that in the $40 - 75°C$ temperature region, the values of $(E/R) \times 10^{-3}$ of the thermoplastic beryllium oxide slips examined are in the range of $1.5 - 21.5$ and correspond to the activation energies of well moistened clays [7]. This suggests that the nature of the disperse systems studied is determined by the sorption reaction of the solid and liquid phases and the character of the deformation behavior of ultrasound-treated and untreated oxide – thermoplastic binder pastes is similar to the behavior of disperse systems based on aqueous solutions of polymers, i.e., systems with developed coagulation bonds [7, 8].

The effect of the specific effects that accompany propagation of ultrasound waves in heterophase disperse systems thus destroys the initial coagulation structure and increases the temperature of beryllium oxide – thermoplastic binder molding systems in the hot molding process temperature range. The change in the plastic strength of thermoplastic slips that takes place in ultrasound treatment due to dissipative heat release can be characterized with the equation for a thermoactivation process.

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